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Global Water Requirements of Future Agriculture: Using WATERSIM

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Abstract

Currently, agriculture is the biggest consumer of water globally. About 60% of global consumptive water demand is from the agriculture sector. With the world population increasing to about 9 billion, and the per capita GDP rising, the demand for domestic and industrial water will increase in future and compete with the agriculture water demand. Changing climate will exert additional pressure on the agriculture sector. For this study, WATERSIM, a water accounting and global food trade model, was run for three socio-economic scenarios and two climate change scenarios to analyse the water demand of the agriculture sector till 2050. The changes in the agriculture sector's consumptive water demand due to changing population and GDP is examined in relation to other sectors (domestic, industrial and livestock). The increase in water requirement of the agriculture sector under different climate change scenarios is also analysed at regional and global scales.

3.1 Back on the Food Agenda

During the last half of the 20th century, global agriculture grew at roughly 2.1–2.3% annually in terms of value (Lundqvist, 2010). Global yields also showed upward trends, on average, although there is a gap in the actual yield between developed and developing countries. Cultivated land (food-crop and non-food-crop land) has also increased by about 12% from 1961 to 2000 (INRA and CIRAD, 2009). The gains in food productivity, which was higher than the growth rate of the human population, led to a fall in prices of most food commodities. With growing per capita income of the population and falling food prices, the food became more accessible, the average per capita food availability in developing countries rose from 2110 kcal per person day^{-1} to about 2650 kcal per person day^{-1} from 1976 to 2006 (FAO, 2006). The increase in food production can be mainly attributed to improvement in technology (for example: Green Revolution) and investment in agricultural infrastructure. As policy makers became more complacent, their focus shifted to other issues. The waning interest in agriculture led to falling investment in the sector in general. The World Bank figures on investment in irrigation shows the drastic reduction since the early 1990s (Fig. 3.1).

Encouraged by the positive trends in falling world hunger, the global community at the 1996 World Summit on Food Security agreed to set a goal to halve the number of people who suffer from hunger by 2015 (from 1990). In 2000, at the Millennium Summit of the United Nations, the member states agreed to halve the proportion of people who suffer from hunger by 2015. One difference in the goals is that while the World Summit talked about halving the absolute number of people, the Millennium

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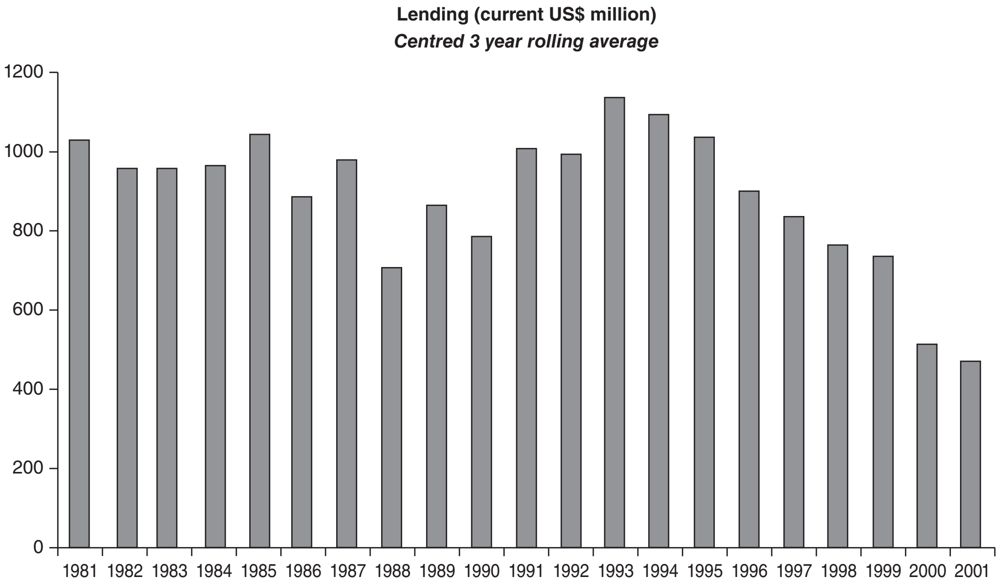


Fig. 3.1. World Bank lending for irrigation (from FAO Corporate Document Repository: The Irrigation Challenge, Issue Paper 4, 2003).

Summit talked about halving the proportion of people suffering from hunger. For the first few years the trends were heading in the right direction: the under-nourished population decreased from 20% in 1990–1992 to 16% in 2005–2007. Although food reached more people than before, the actual number of people who were undernourished went up from 817 million in 1990–1992 to 830 million in 2005–2007 (UN, 2010). The numbers of under-nourished were going down till 2000–2002 and then the progress stopped, and culminated in the 2007–2008 food crises. In a span of just a few months the prices of cereals almost doubled. There were riots in as many as 30 countries. Along with the reduced interest and investment in agriculture, the other reasons that led to this crisis were drastic increases in global fuel prices, higher demand for biofuels and the precautionary trade restrictions put in place by some countries (Nelson *et al.*, 2010). Cereal prices did fall after the crisis but started to rise again in 2009. The 2007–2008 crisis was a wakeup call to the policy makers from around the globe not to lose focus on agriculture. Food security issues are back on the agenda of the global community.

Over the last decade there has been impetus in looking at the future trends in agriculture production, food commodities prices and the impact of food availability on human wellbeing. This chapter reviews the recent studies carried out on projecting future food demand. It then introduces a model developed by the International Water Management Institute (IWMI), the Water, Agriculture, Technology, Environmental and Resource Simulation Model (WATERSIM), to show how modelling can be used to analyse complex issues of food security and water security in the future. The model links river basin hydrology with food trade between the economic regions of the world. It is used to analyse three socio-economic scenarios, developed based on population growth and GDP growth, and focuses on water demands till 2050. The analysis looks at the competition for water between agriculture, industry and domestic demand. It looks at the consumptive use of water in the three sectors for all the three scenarios. Finally, it calculates the change in consumptive water demand for the agriculture sector due to climate change.

3.2 Looking Into the Future

There have been multiple studies that have looked at food security issues. Due to the complexity of the issue, these studies have focused on scenario analysis. Scenario analysis is a process in which different possible outcomes are analysed by changing possible variables that can impact the future world. It is especially helpful where the future outcome is dependent on many complex systems. Due to the uncertainties within such systems and complexity of their interactions with each other, it is difficult to predict the future direction. In such cases, scenario analysis helps in developing stories that define the boundary conditions for a likely future state of affairs, based on some rational assumptions. By considering the most pessimistic and the most optimistic scenarios, we can obtain a range of possible outcomes for the future. Conditions under different scenarios are forecast using models that rely on historic data for calibration and validation and then run for future timelines. Recent high profile examples of such scenario developments are: (i) Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) that created four storylines – A1, A2, B1 and B2 – by combining economic growth, environmental values, increased globalization and increased regionalization; and (ii) global scenarios created for the Millennium Ecosystem Assessment – Global Orchestration (GO), Order from Strength, Techno garden and Adapting Mosaic – by combining globalization, regionalization, reactivity and proactivity to ecosystem problems. The goal of such scenario development is to provide basic guidelines for interdisciplinary research. It also provides a uniform framework so that it is easy to interpret and compare outputs from different research work. Making a storyline helps policy makers to understand the situation better.

For agriculture, Agrimonde developed scenarios to analyse the future for feeding the world by 2050 (INRA and CIRAD, 2009). The panel for the Agrimonde study created a scenario called Agrimonde GO (AGO), which is a modified version of the MA GO scenario (depicting the pathway of liberalized global trade with major technological development leading to large reductions in poverty and malnutrition but reactive approach to the increasing risk to the ecosystem). They then developed another scenario, called Agrimonde 1 (AG1), which shows the future pathway of a world system that uses technology to advance agriculture production especially in those countries that lack the capital required to invest in such production systems, while also being proactive in terms of protecting the ecosystem. According to the analysis, the food consumption by 2050 will reach between 3000 kcal per capita day^{-1} (AG1 scenario) and 3590 kcal per capita day^{-1} (AGO scenario). The increase in the food demand is met by increasing the cultivated land (39%, AG1 scenario to 23%, AGO scenario) area and improvement in the crop yields.

The International Food Policy Research Institute (IFPRI) has also developed scenarios and conducted analysis to look at the possible future resource limitations and policy options. In a study conducted in 2002 (Rosegrant *et al*., 2002), IFPRI in collaboration with IWMI looked at the linkage between food security and water security till 2025. Three scenarios were explored in this analysis: (i) the Business-As-Usual scenario (BAU); (ii) the Water-Crisis scenario (CRI); and (iii) the Sustainable Water Use scenario (SUS). BAU assumes similar agriculture policies and investments in future as prevalent in 2002, with falling interest in the agriculture sector, lack of high technological innovations, and limited institutional and management reforms, and a greater pressure from the environment to meet its demand. For CRI, it is presumed that due to a failing economy, the budget cuts will hit investments in water and the agriculture sector and the irrigation systems would be turned over to the farmers without proper capacity building. Due to an increase in deforestation and lack of proper watershed management plans, the land quality will deteriorate further. Lack of proper research would lead to very little increase in food productivity. For SUS, it is assumed that there is greater protection for the environment and greater social equity. It considers more investment in R&D, technology development and adequate water pricing to improve agricultural productivity and to conserve water. These scenarios were analysed using a global modelling framework, which was made up of a combination of two models: the International Model for Policy Analysis of Agriculture Commodities and Trade (IMPACT) and Water Simulation Model (WSM). Their analysis showed that the competition between agriculture and other sectors will increase in future due to a rapid increase in industrial and domestic water demand, which would affect developing countries more. For the BAU scenario, the future food production will increase due to increase in crop yields and improvement in water productivity. The higher demand for water will also put pressure on the water needed for the ecosystem services. For the CRI scenario, water scarcity would increase, thus not only endangering ecosystem services but also constraining food production. This will lead to a large jump in food commodity prices, thus negatively impacting the drive against malnutrition.

In a later study conducted by IFPRI (Nelson *et al*., 2010), the focus was once more on food security but it also looked at climate change till 2050. In this global study, the scenarios created were based on changes in population, gross domestic product (GDP) and climate change. For the population and GDP, three scenarios were considered: (i) pessimistic, i.e. low GDP growth rate with high population increase; (ii) baseline, i.e. average GDP growth rate (based on World Bank EACC study) with medium population growth; and (iii) optimistic, i.e. high GDP growth rate with low population growth rates. For the climate change, the study considered four scenarios, i.e. CSIRO[1] A1B and CSIRO B1 (depicting a dry and relatively cool future), MIROC[2] A1B and MIROC B1 (depicting a wet and relatively warm future). Their findings suggest imbalance in supply and demand of food commodities till 2050 leading to an increase in food prices. The buying capacity of people will increase, in general, but due to the negative impact of climate change and changing diets of the increasing population, the demand will outpace supply, leading to an increase in prices (calculated as 31.2% for rice to 100.7% for maize). In this scenario, this imbalance can be reduced by proper R&D and improved global trade. There will be little scope to increase the agriculture area in future (without impacting the environment) but there is still scope to improve crop yields (for e.g. 2% per year for maize, wheat and cassava). Even in the best case scenario, prices still increase by 18.4% for rice to 34.1% for maize. Overall the malnutrition among children under 5 years of age will decrease till 2050 but the percentage of reduction varies from 45% in the optimistic scenario to only 2% in the pessimistic scenario. Climate change will cause an increase of 8.5–10.3% of malnutrition among the same group compared to their ‘perfect mitigation’ case. The study suggests a more severe impact of climate change after 2050, when the population will stabilize but the impact of climate change can be substantial.

Another major study by the Food and Agriculture Organization of the United Nations (FAO) in 2003 looked at world agriculture at 2015/2030 (FAO, 2003), and has been updated twice, first in 2006 to extend the time period to 2030/2050 (FAO, 2006) and second, in 2012, for the same time period but with more recent data (FAO, 2012). In this study, only one scenario was considered, where, at global scale, the growth in future agriculture will slow down because of the stabilization in future food demand as the population stabilizes and the diets converge towards 3000 plus kcal/capita day^{-1}. The growth in the agriculture sector will be about 60% from 2005/7 to 2050 for its baseline scenario. But the global numbers hide regional variations. Although the global population stabilizes, there will be growth in developing countries, which are already undernourished, that will be counterbalanced with decline in the population of developed nations. This will turn many developing countries from net exporter to net importer. Similar to the IFPRI study, their analysis shows that most of the future increase in food production will come from improved crop yields. There would be some addition to agriculture land, which would come at the expense of the pasture land, and is expected to increase by about 70 million ha by 2050. The analysis does not see any persistent threat to agriculture due to climate change at least till 2030 (FAO, 2003). There may be local/regional variation that can be mitigated by agricultural management. Overall, in the short term, the agriculture sector might have a positive impact on climate change due to carbon sequestration.

A similar global study was conducted by IWMI in 2007 to answer the question of whether there is enough water to produce food to meet the demands of the growing population till 2050 (IWMI, 2007). In short, the outcome of the work suggested that there is enough fresh water to meet the demand of growing agriculture, but only with proper water management and improvement in yield, especially in rainfed agriculture. More than 75% of the increase in food demand can possibly be met by improvement in yields rather than increase in agricultural area, which will also help safeguard ecosystems from further damage. Currently 70% of the global freshwater withdrawal is for irrigation, but the proportion of water withdrawal for domestic and industrial uses will increase in future. If water productivity is not considered, the amount of water consumed (evapotranspiration) by agriculture will increase by 70–90% by 2050 (i.e. from 7130 km^3 to 12,000–13,500 km^3). The IWMI analysis considered four scenarios: (i) rainfed scenario, by investing to increase rainfed agriculture production by increasing productivity, improving land management and increasing rainfed agriculture area; (ii) irrigation scenario, by investing in irrigation to provide more irrigated water and improving irrigation efficiency; (iii) trade scenario, by having more liberal trade policies between countries; and (iv) comprehensive assessment scenario, by incorporating features from all the above scenarios to suit each region. In the rainfed scenario, a 1% increase in agriculture yield per year can help in meeting the future food demand with only a 7% increase in agriculture area. A 40% increase in irrigation withdrawal in the irrigation scenario could help irrigated agriculture cater to 55% of total food demand in 2050. On the other hand, trade could help bridge gaps in the regions where supplies cannot meet the demands of a growing population. A combination of all these scenarios can lead to the most sustainable path to meet future food demand with the least damage to the ecosystem. But even in such a scenario, the water withdrawals for irrigation would increase by 13% and cropped area would increase by 9%.

As seen in the 2007/2008 crises, biofuels can play a critical role in the future agriculture scene. Analysis done by the International Institute for Applied System Analysis (IIASSA) shows that based on the current biofuel targets, biofuels will provide 12% of transportation fuel in developed countries and 8% in developing countries by 2030. Due to the increase in demand for biofuels, food prices would rise by 30% by 2020, creating a risk of under-nourishment of 140–150 million additional people (OFID, 2009). The increased demand for biofuels will also put pressure on agriculture land. To meet the future biofuel demand till 2030, an additional 37 million ha of land would be required. As discussed before, global agriculture trade and improvement in water productivity, crop yields and water efficiency can help reduce pressure on natural resources while also meeting demands in the future.

Except for the IWMI study, most of the above studies have focused on food but not so much on the resources behind it per se. Water is one of the most critical resources for food production. Water security is closely linked to food security. How would an increase in future food demand impact the water sector and vice versa? A recent study done by the Organization for Economic Co-operation and Development (OECD) to look at environmental issues till 2050 predicts that if no action is taken, then by 2050, about 40% of the world population will be living in the river basins that are under severe water stress (OECD, 2012). The water demand in 2050 will increase by 55%, most of which will be coming from the industrial and domestic sector. The higher temperature due to climate change could exacerbate the water scarcity problem even more.

3.3 Developing Scenarios

To develop scenarios, the variables that impact the situation need to be identified. There are multiple variables or drivers that impact food security. They are also common to water security. The next section looks at these drivers of change.

3.4 Defining Drivers of Change

Drivers of change are the entities that can impact and modify the path of the future course of action, thus causing a change in the future outcomes. Such drivers may fall into one of the following categories: social or cultural, political, technological, natural and economic. Hazell and Wood (2008) classify drivers of change in agriculture at three scales, global, country and local. The global scale drivers include trade, energy prices and agriculture policies. Country scale drivers include per capita income, urbanization and changing market chains. The local scale drivers are poverty, population pressure, health, technology, property rights, infrastructure and market access, and non-farm opportunities. Some of the examples of major drivers of change in the agriculture sector are population, GDP and climate change, which are also considered here. The global population is expected to reach 9 billion by 2050 and then stabilize. Although there will not be a net increase in the global population, there will be spatial variation in future population growth. Most of the future population growth will take place in the developing countries, which will be countered by the negative growth in the developed countries. Most of the future urbanization will also take place in developing countries. These changing dynamics of the global population will have consequences on the future global players in the food trade, which will also have an impact on natural resources in the developing world. In these regions the water demand for domestic consumption and food demand will increase substantially. The increasing GDP could lead to more buying power for the people, thus changing their dietary habits. Existing data show that in general, diets shift from cereal based to more meat based as the economic conditions of people improve. This could also have serious implications on water resources, as a meat-based diet requires more water than a cereal-based diet. Finally, climate change would have a direct impact on agriculture. The changing rainfall pattern and the increasing temperature will impact the water requirement and crop yields of the crops.

Three socio-economic scenarios were considered. The socio-economic scenarios were created from the GDP and population data provided by IFPRI and used in their study (Nelson *et al*., 2010). The BAU scenario considers regular growth in GDP and population (i.e. 2008 UN population forecast, medium variant). The optimistic scenario (OPT) considers higher GDP growth (i.e. the highest of the GDP scenarios in the Millennium Ecosystem Assessment GDP scenarios including BAU scenario) and lower population growth (i.e. 2008 UN population forecast, low variant), whereas the pessimistic scenario (PES) considers lower GDP growth (i.e. the lowest of the GDP scenarios in the Millennium Ecosystem Assessment GDP scenarios including the BAU scenario) with higher population growth (i.e. 2008 UN population forecast, high variant) (Nelson *et al*., 2010). Globally, for the BAU scenario, the GDP is predicted to grow by 9.14% annually and population by 1.2% by 2050, which would lead to annual per capita GDP growth of 6.3%. For OPT, by the year 2050 the global GDP will increase by 11.1% and population by 0.77% annually, leading to an annual per capita GDP growth of 9.93%. For PES, the annual growth is projected to be 4.11%, 1.78% and 1.86%, respectively.

Two climate change scenarios, SRESA2 and SRESB1, were also considered. SRESA2 describes a situation in which the world is made up of heterogeneous regional economies that are growing at a slower pace but the global population is increasing. SRESB1 describes a more globalized world, where global population will peak in the mid-century and then decline, and the global economy will move towards less resource-intensive but clean technologies. For each climate change scenario, the hydrological model was run using climate data from four global circulation models (GCMs). These are MPI-ECHAM5, MIROC3.2, CSIRO Mk 3.0 and CNRM-CM3.[3] The output from the GCM runs were averaged to obtain a single output for each of the two climate change scenarios.

In the WATERSIM model, global trade, through prices, controls the food demand and to some extent the supply (as there is positive shift in yields and increase in area due to rising prices). For the current project, the year 2000 was considered the base year and the model was run till 2050. The hydrological data of the model were acquired from the Lund-Potsdam-Jena managed Land (LPJmL) global hydrological model developed by Potsdam Institute for Climate Impact Research (PIK), Germany. The baseline hydrological data were considered as 30-year average monthly values. The average values from 1970 to 2000 were used in this case.

3.5 Water-accounting and Economic Model – WATERSIM

WATERSIM is an integrated water accounting and food trade balance model, developed by IWMI to answer questions related to future availability of water and food security issues at regional and global scales. Thus the model consists of two modules: (i) water supply and demand module, which is based on IWMI's water accounting framework (Molden, 1997); and (ii) food demand and supply module, which is adapted from IFPRI's IMPACT model (Fig. 3.2).

For the 'water supply and demand' module, the world is divided into 125 prominent river basins. Monthly 'water supply' information is supplied to the model as an input. The water supply consists of precipitation, surface runoff and groundwater recharge. These inputs are acquired from a

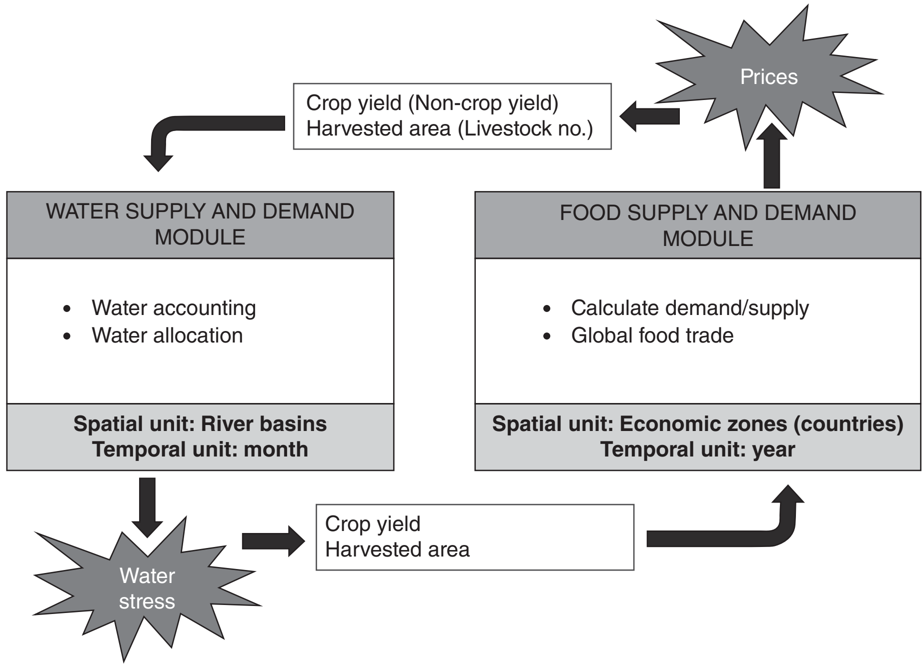


Fig. 3.2. WATERSIM framework.

third-party global hydrological model. The precipitation information is used to calculate the effective precipitation (i.e. the precipitation that is converted to crop evapotranspiration; ET) for the crops. Effective precipitation is calculated by the SCS method (USDA-SCS, 1967). Each basin is defined with a surface storage capacity and groundwater pumping capacity, i.e. the maximum amount of water that can be stored in surface storage structures and pumped out of aquifers, respectively. The surface runoff is used to see how much water is available at monthly time steps to fill the available surface storage capacity. The model conducts surface water balance, wherein the surface runoff is used to fill up available storage capacity and the remaining flows out of the basin as an 'overflow' and is unavailable to meet the water demands for that basin. The 'groundwater recharge potential' (i.e. proportion of water withdrawal that is met by groundwater) for each region is used to calculate the potential water available in the form of groundwater. In the model, the water actually consumed in each sector is controlled by the depletion factor. Depletion factor is defined as a ratio between water that is consumed to water that is supplied. During the optimization process, the depletion factor is allowed to vary between 0.4 and 0.75. Water not depleted is returned to the flow going out of the basin. Some of the irrigation water helps in recharging the groundwater and is accounted for in the model. The 'water demand' in the module is divided into four sectors: domestic, industrial, livestock and irrigation water demand. Domestic and industrial water demands are a function of population and per capita income. The relationships between domestic and industrial water demands and population and per capita income were developed by IFPRI by regression analysis of historic data. Base-year data are used to calculate the intercepts. The livestock water demand is dependent upon the number of livestock multiplied by the water demand per livestock. The agriculture water demand is irrigation water demand, which is calculated as the difference between the crop potential evapotranspiration and the effective rainfall in the irrigated harvested area. Some of the constraints such as environmental flow requirements and flow committed due to treaties are also considered.

Once the supply and consumptive demand of water is calculated at a river basin for each month, an optimization routine is run to maximize the ratio of depletive supply (i.e. the available water that is used to meet the consumptive demand) over consumptive water demand. The range of this ratio is from 0 to 1; 0 implies that no demand is met and 1 implies that all the demand is met. The routine is based on a reservoir operation model, in which the goal is to maximize the reservoir yield while also trying to maximize the storage. The optimization routine also attempts to maximize surface storage while meeting the environmental flow and any committed flow constraints. If for some month the water available is less than the total water demand, the depletive supply is partitioned between different sectors either proportional to each sector's demand or on priority basis (i.e. highest priority to domestic, then industrial, then livestock and finally to agriculture). Within the agriculture sector, the scarce water is further allocated to crops based on the profitability, sensitivity to water stress and net irrigation demand of the crop. The reduction in available water for crops leads to reduction in crop area and also reduction in yields.

The modified crop area and yields from the water supply and demand module provides the total supply of crop commodities for a year. The supply of commodities is effectively harvested area of crops multiplied by the yields of the crop. In the case of livestock, it is the number of livestock multiplied by the yields per livestock. The area and yields of each commodity that is calculated in the 'water demand and supply' module is fed into the 'food demand and supply' module of WATERSIM.

For the 'food demand and supply', the globe is divided into 115 economic regions. The model is based on the concept of partial equilibrium and connects the regions through trade. The equilibrium in trade is reached at annual basis. Demand is a function of price, income and population and the supply is influenced by prices and income. The difference between supply and demand generates excess supply or demand, which is aggregated at global level. This helps determine the world market clearing price, i.e. the equilibrium world price at which the total amount of imports is equal to the total amount of exports. This module also determines the new yields and harvested areas as influenced by price and income, which feed back into the water supply and demand module.

Multiple iterations are done between the 'water supply and demand' module and the 'food supply and demand' module for each year till equilibrium is developed. After the model has reached the equilibrium, the final supply and demand of commodities is considered. The working unit of WATERSIM is called a Food Producing Unit (FPU), which is the intersection of the 125 river basins and 115 economic zones. There are 281 FPUs in WATERSIM.

3.6 What the Future Holds

3.6.1 Water resource implications

WATERSIM calculates the consumptive water demand for each of the sectors. Consumptive water demand is the demand of actual water required for consumption, i.e. water that is lost by evaporation and/or transpiration or degraded in quality as to not be useful without substantial treatment. In the agricultural sector, the consumptive water can be classified in two groups, blue water and green water. Blue water is the water that is extracted from surface or groundwater storage whereas green water is the water that is retained in the soil (as soil moisture) due to precipitation. Thus blue water refers to water supplied by irrigation. Figure 3.3a shows consumptive water demand for the three scenarios, for different regions of the world, considering consistent climatic conditions. Figure 3.3b shows the same demand but divided by the sectors. As per the model, the consumptive water demand at global scale will increase from about 2400 km^3 in 2010 to about 5250 km^3 in 2050 for the BAU scenario. For the OPT socio-economic scenario, the total consumptive water demand increases to 7230 km^3 by 2050 whereas for the PES scenario, it is as little as 3820 km^3. In the year 2010, the percentage of consumptive water demand for agriculture is about 72% of the total demand. Due to increase in population and GDP, this demands goes down to 37% in BAU, 27% in OPT socio-economic condition and 50% in the case of PES socio-economic condition. Thus the greatest increase in demand for consumptive water comes from the domestic and industrial sectors. Even among the two sectors, the demand for the industrial sector outpaces the demand from the other sectors. IWMI's Comprehensive Assessment Report (IWMI, 2007) had predicted that the non-agriculture withdrawal of water is expected to increase by a factor of 2.2 from 2000 to 2050. At this stage, the model does not consider increase in water use efficiency in the domestic and industrial sectors. In reality, as the economics of the countries improve, there would be a much greater improvement in their water use efficiency.

In this model run, the increase in agriculture area was not based on historic trends. Instead, the change in the agriculture area is because of the changes in the prices of crops in the 'food supply and demand' module. In this case the model assumes perfect trade conditions and does not consider any trade barriers. The harvested area of the crops changes from 1050 million ha to 1220 million ha, which is an increase of about 16%. It is to be noted that this is an increase in harvested area and not an increase in agriculture area (which should be less than this). Consequently, the green water demand also goes up from 2010 to 2050. The green water usage (i.e. effective rainfall used in rainfed and irrigated crops) for 2010 is about 4580 km^3 and it increases to 5450 km^3 by 2050. This increase in green water usage is due to the increase in the harvested area for the time period.

Figure 3.4 shows the sectorial water demand for the BAU scenario. There is a big variation in regions. While in OECD countries the agriculture water demand drops from less than 40% to less than 20%, in MNA countries it still constitutes close to 90% of total water demand till 2050. In South Asia, the agriculture water demand reduces from 90% to about 70% by the year 2050. For all these regions, the trend is towards higher water demand for the industrial and domestic sectors, which would lead to higher competition with agriculture demand.

The environmental demand for the regions is calculated based on the

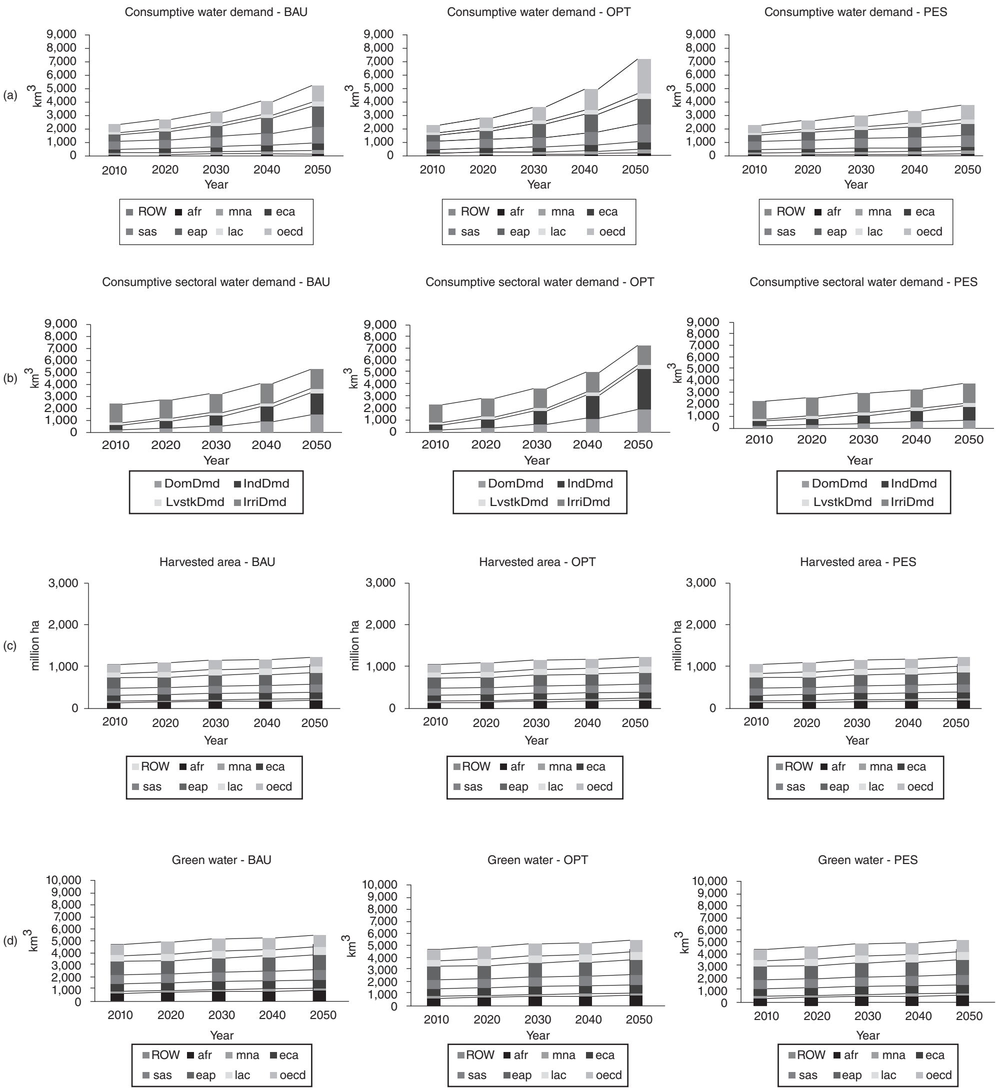


Fig. 3.3. WATERSIM outputs for baseline climate scenarios for three socio-economic conditions: business as usual (BAU), optimistic (OPT) and pessimistic (PES) scenarios. (a) Consumptive water demand by regions; (b) consumptive water demand by sectors; (c) harvested area; and (d) green water. ■ ROW, rest of world; ■ afr, sub-Saharan Africa; ■ mna, Middle East and North Africa; ■ eca, Eastern Europe and Central Asia; ■ sas, South Asia; ■ eap, East Asia and Pacific; ■ lac, Latin America and Caribbean; ■ OECD, Organisation for Economic Co-operation and Development; ■ DomDmd, domestic demand; ■ IndDMD, industry demand; ■ LvstkDmd, livestock demand; ■ IrriDmd, irrigation demand.

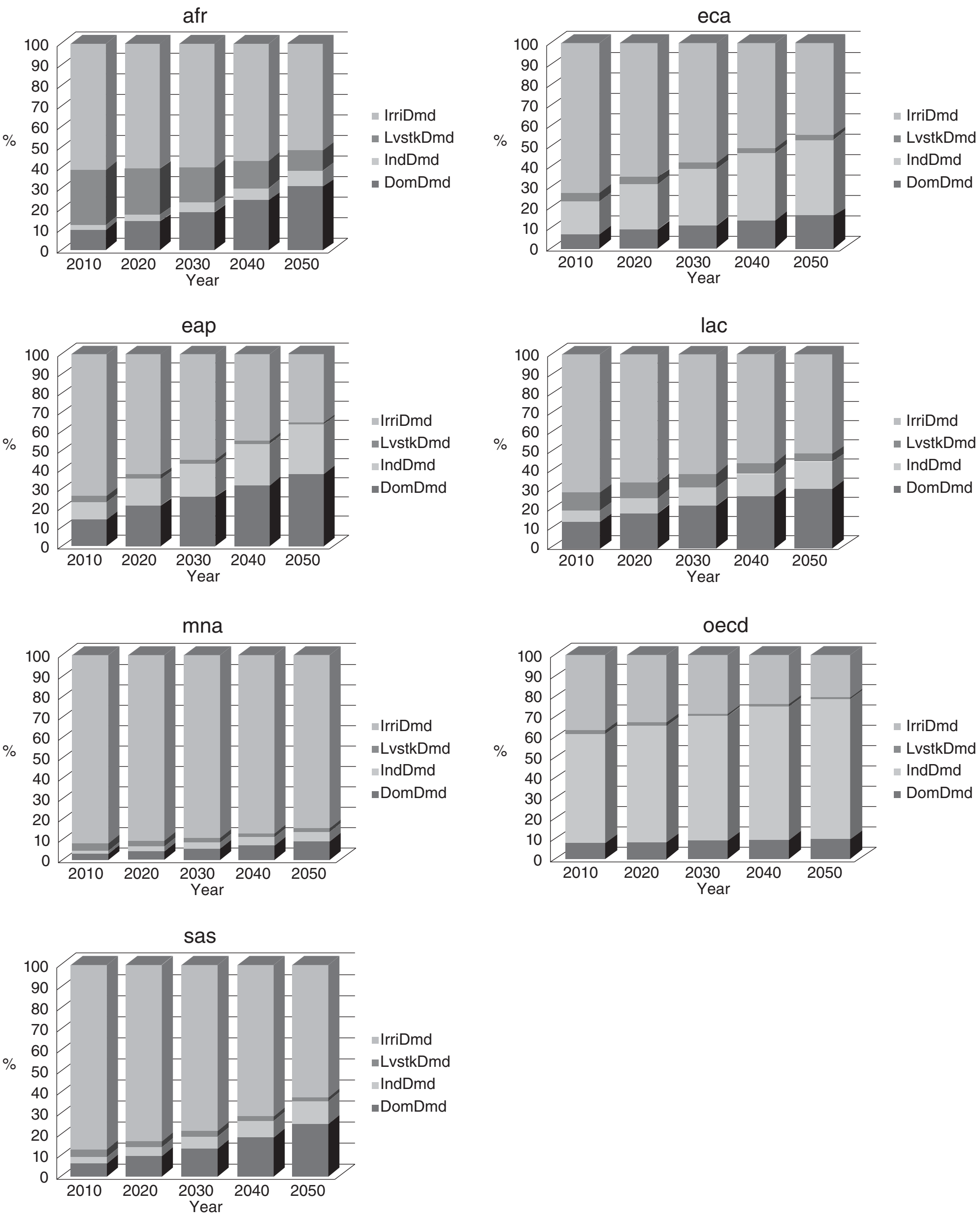


Fig. 3.4. Sectorial breakdown of consumptive water demand for the BAU scenario till 2050 (for abbreviations, see Fig. 3.3).

environmental flow requirement as per Smakhtin *et al*. (2004). Figure 3.5 shows environmental demand for different regions in the world. It varies from about 20% for the ‘Rest of the World’ to about 33% for ECA region. The highest environment demand of about 3500 km^3 is for the LAC region and the least (about 40 km^3) for the MNA region.

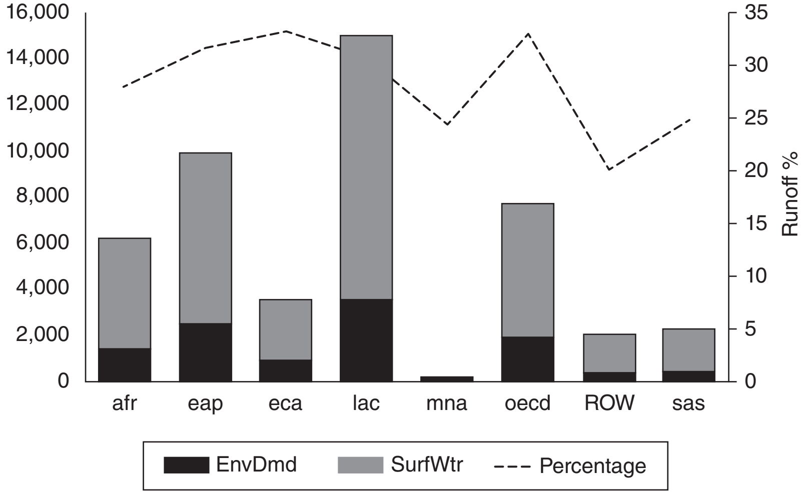


Fig. 3.5. Environmental demand at regional level (in absolute values and in percentage of the total surface runoff (EnvDmd, environmental demand; SurfWtr, surface water; for other abbreviations, see Fig. 3.3).

3.6.2 Climate change scenarios

WATERSIM was then run for SRESA2 (A2) and SRESB1 (B1) climate change scenarios. Figure 3.6 shows total rainfall, potential evapotranspiration (PET) and effective precipitation (i.e. rainfall that is converted to ET by the crops), and difference between PET and effective precipitation at the global scale for A2 and B1 scenarios (using average of four GCMs as discussed above) as compared to the baseline.

The analysis shows that at the global scale, there is no clear trend in the total rainfall. On the other hand, PET, which is dependent upon the temperature, increases, with a much sharper increase after 2040. This leads to higher effective precipitation (i.e. increased water consumption by crops, which depends both on increased precipitation and higher temperature). But if the difference between PET and effective precipitation (which represents the shortfall in water requirement for agriculture, both rainfed and irrigated) is considered, it is much higher during the A2 and B1 climate scenarios as compared to the baseline. Also A2 climate change scenario has a greater shortfall than the B1 climate change scenario. At the regional level (shown in Fig. 3.7), Africa, East Asia and Pacific, Eastern Europe and Central Asia show lower rainfall till 2020 and then increase till the mid-2040s before decreasing again. The Middle East and North Africa receive lower rainfall whereas there are no discernible trends for OECD and South Asia. The difference between PET and effective precipitation is above the baseline in most of the regions, which indicates a greater demand for irrigation water in future scenarios.

Based on the analysis done using WATERSIM, for the year 2050, for the irrigated area, the gap between PET and effective rainfall will be about 19% higher than the baseline for the A2 climate change scenario, whereas it will be about 16% higher for B1 climate change scenario. This will put extra stress on demand for irrigation water. The changes in the cropping pattern or changes in the length of cropping season have not been considered in this study as that may impact the actual requirement for irrigated water. At regional level, the gap between PET and effective rainfall due to climate change (on average, from 2010 to 2050) is shown in Table 3.1.

The climate change will have a larger impact on water demand for agriculture in Africa and the OECD regions and lesser impact in Eastern Europe and Central Asia.

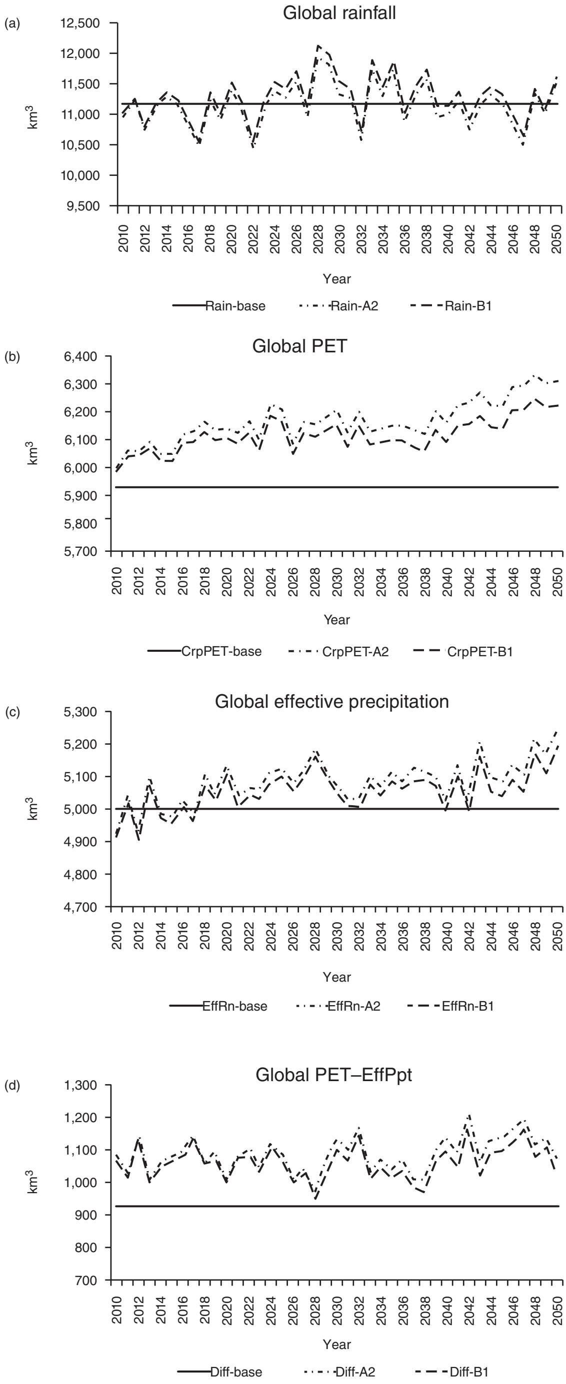
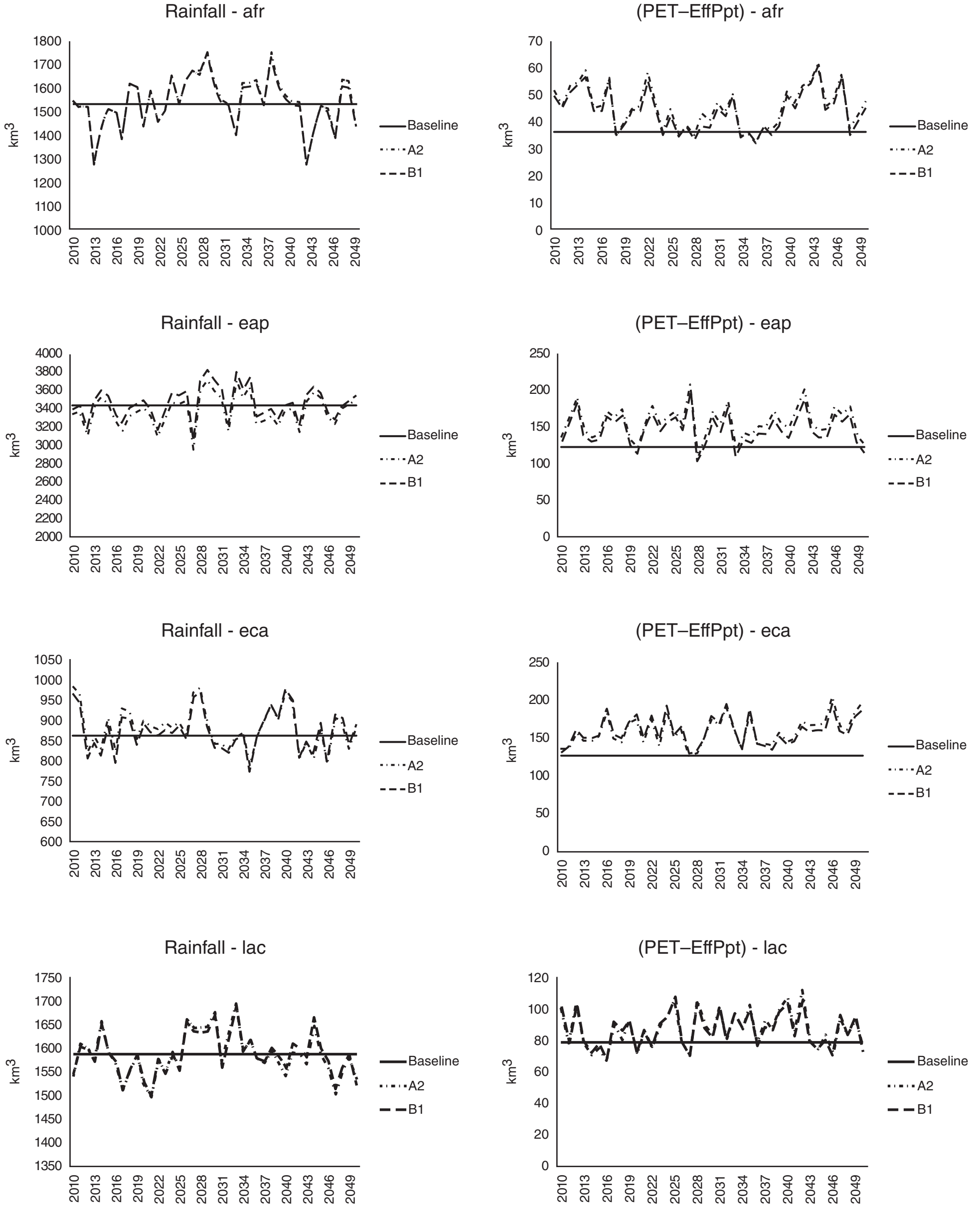


Fig. 3.6. Changes in (a) rainfall, (b) PET, (c) effective precipitation, and (d) difference between PET and effective precipitation at global scale.

3.7 Conclusions

After the first green revolution in the 1960s, the world became complacent with the progress in the agriculture sector. They were encouraged by the falling food commodity prices and improving food consumption of the global population. However, since the beginning of the 21st century, the trends in food prices have reversed. Since then, many studies have been conducted by renowned organizations from around the world to look



Continued

Fig. 3.7. Changes in rainfall and difference between PET and effective precipitation at regional level (for abbreviations, see Fig. 3.3).

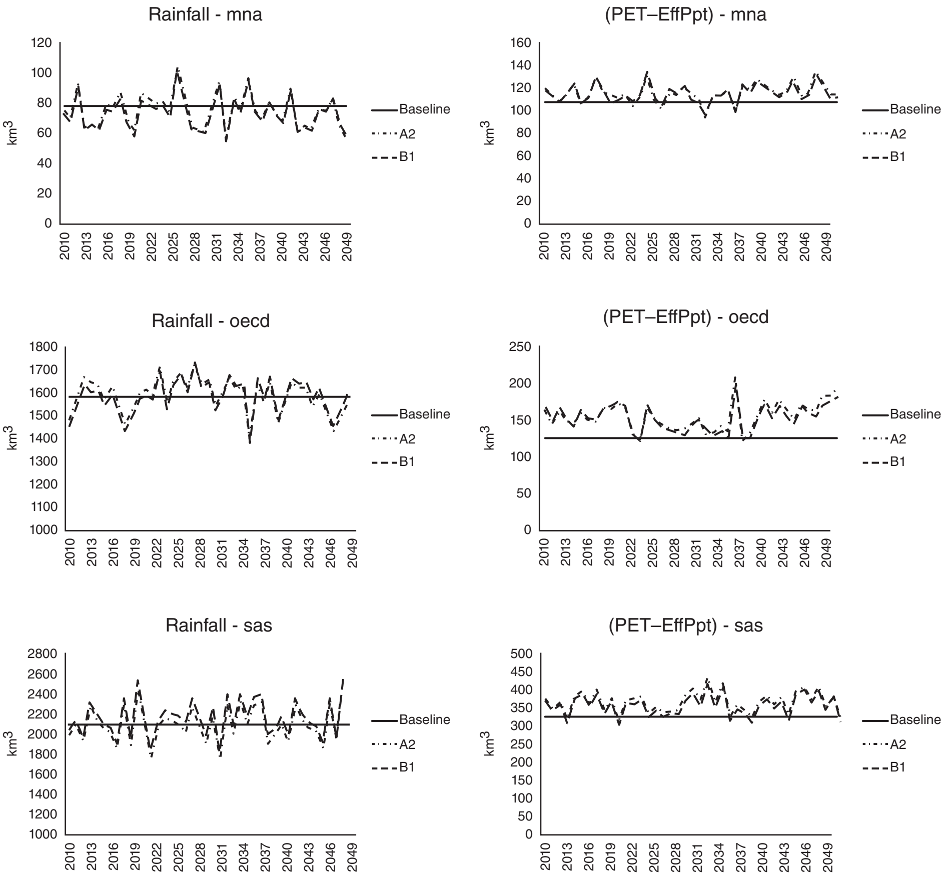


Fig. 3.7. Continued.

Table 3.1. Percentage change (from baseline) in the gap between PET and effective rainfall in 2050.

Regions	A2 (% increase)	B1 (% increase)
Sub-Saharan Africa	25.07	21.64
East Asia and Pacific	26.58	19.34
Eastern Europe and Central Asia	26.03	25.72
Latin America and Caribbean	11.04	10.70
Middle East and North Africa	7.52	6.89
OECD	25.30	23.33
South Asia	10.58	7.72

at future food and natural resources scenarios. The common message that comes out of all these studies is that with proper management of food cycles, technical innovation and the wise use of natural resources, the future demand for the population can be met, which includes reducing malnourishment. There is a large scope for improving yields in rainfed agriculture and in reducing waste within the food cycle. The globalization of food trade will also help to mitigate some of the shortfalls in regions with increasing populations.

Water is a critical resource that will be impacted by the increasing population, GDP and climate change. The water demand for the industrial and domestic sector will increase (without considering the efficiency) due to increase in population and per capita income. This would lead to higher competition with the agriculture sector from the other sectors. The results emphasize the growing demand that will come from industrial and domestic users, particularly under an 'optimistic' scenario of limited population growth but significantly increasing GDP per capita. Climate change scenarios suggest that if we are to maintain optimum yields, between 16% and 19% more irrigation water will be required on average due to higher evaporative demand. This estimate is more conservative as the growing seasons of the crops may shorten, which has not been considered in this research. The impact of climate change may become much more dominant after 2050, although most of the current studies have only focused till 2050.

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Notes

[1] Commonwealth Scientific and Industrial Research Organization.

[2] Medium Resolution General Circulation Model.

[3] MPI-ECHAM5: Max Planck Institute for Meteorology – European Centre for Medium-Range Weather Forecasts (ECMWF) Hamburg; MIROC3.2: Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change; CSIRO Mk 3.0: The Commonwealth Scientific and Industrial Research Organisation; CNRM-CM3: Center National Weather Research.

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